Long-Period Tidal Variations of the Earth's Rotation Rate

Shailen D. Desai (Shailen.D.Desai@jpl.nasa.gov), and Richard S. Gross, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, U.S.A.
John M. Wahr, University of Colorado, Boulder, CO, U.S.A.

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Abstract

Long-period tidal variations of the Earth's rotation rate are caused by the redistribution of mass associated with the respective elastic solid Earth tides, the ocean tide heights, and the anelasticity of the Earth's mantle, and by the relative angular momentum associated with the long-period ocean tide currents. The dominant contribution from the elastic solid Earth tides are known to high accuracy from theoretical and numerical analyses. However, the lack of global observations of the long-period ocean tides has limited the accuracy of predicted contributions from these ocean tides. The anelastic response of the mantle at frequencies smaller than the seismic frequencies are somewhat uncertain but could be inferred from observations of the long-period tidal variations of the Earth's rotation rate with improved predictions of the contribution from the ocean tides.

Here, almost global empirical models of the monthly and fortnightly ocean tides estimated from TOPEX/POSEIDON and Geosat Exact Repeat Mission altimetry are used to predict their respective contributions to variations of the Earth's rotation rate. Observed long-period tidal variations of the Earth's rotation rate are estimated from the SPACE98 time series and the residual between these observations and the sum total of the predicted contributions from the elastic solid Earth tides and the ocean tides is used to infer anelastic properties of the Earth's mantle at the monthly and fortnightly periods.

Long-Period Ocean Tide Models

- Two empirical models of the monthly (Mm) and fortnightly (Mf) ocean tides are estimated from altimetric sea surface height (SSH) data.
- **Model 1** is estimated using SSH data from repeat cycles 10-229 of the TOPEX/POSEIDON (T/P) mission (6.2 years of data starting December 21, 1992).
- **Model 2** is estimated by using SSH data from repeat cycles 1 to 38 of the Geosat Exact Repeat Mission (GERM) (1.8 years of data starting November 8, 1986) to initialize the model, before adding data from repeat cycles 10-229 of the T/P mission.
- **Model 2** assigns the GERM data a weight of $(15/55)^2$ relative to the T/P data.

Tide Gauge Validation of Models

- A subset of 14 Mm and 23 Mf tide gauges from *Miller et al.* [1993] (MLH93) are used to validate the empirical Mm and Mf ocean tide models.

- When using **Model 2** instead of EQO, there is a small increase in energy at Mm of 3 dB, but a distinct reduction in energy at Mf of 17 dB.

Mantle Anelasticity

- The anelastic response of the mantle defines the dissipative response, where the dissipation $Q(\omega)$ at a frequency ω can be related to the dissipation at a reference frequency ωm by a single parameter, α.

$$Q(\omega) = Q(\omega_m)\left(\frac{\omega}{\omega_m}\right)^{\alpha} \qquad (2)$$

- The observed Mm and Mf variations in LOD are estimated from the SPACE98 time series.
- The residual after removing the SE and **Model 2** contributions from the Mm and Mf SPACE98 observations provides the predicted contributions from mantle anelasticity at these frequencies.
- These residuals are compared in **Figure 4** to the anelastic contribution inferred by applying various values of α to the PREM Earth model.
- For Mf, the comparisons indicates $-0.15 < \alpha < 0.20$
- For Mm, the comparisons suggest that the quadrature anelastic contribution inferred by the T/P ocean tide models is too low by approximately $\kappa = 0.005\text{-}0.025$.
- This supports the earlier suggestion that the Mm quadrature motion prediction from the T/P models is too large by approximately 0.01 (see **Figure 3(d)**).

Conclusions

- GERM data appear to improve tide gauge comparisons slightly, but have a minimal effect on rotation rate predictions.
- Improvements are necessary in the Mm motion contributions predicted by the T/P models, particularly the quadrature component, before inferring α at Mm. Tide gauge comparisons suggest further improvements to the Mm empirical model from incoming data.
- Mf predictions for α might be further improved by reducing the scatter in both the ocean tide predictions and the rotation rate observations.

Acknowledgments

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- A revised set of Mm and Mf tide gauge observations for the same set of tide gauges reported by MLH93 is also used to validate the models.
- **Figure 1** illustrates that the residual variance between tide gauge observations and the empirical models continues to decrease (improve) as incoming T/P data are used to update the models.
- Inclusion of GERM data has an insignificant effect on the Mm model, but reduces (improves) the Mf residual variance by approximately 0.1 mm^2.
- Mf residual variances with the revised tide gauge observations are slightly smaller (better) by approximately 0.3 mm^2 than with the MLH93 observations.
- Residual variances for Mm and Mf are of the order 2.3 mm^2 and 1.6-2.1 mm^2, or **14% and 4-5% of the observed variance**, respectively.

Predicted Ocean Tide Contribution to Variations in Earth's Rotation Rate

- Empirical models are restricted to within ±66 degrees latitude, but are extended globally with the *Schwiderski* [1980] hydrodynamic model poleward of ±66 degrees.
- The mass contribution to variations in rotation rate is computed from the degree 2 zonal spherical harmonic component of the ocean tide height model.
- The motion contribution is computed from ocean tide currents that are derived by applying frictionless Laplace tidal equations to the tide height models.
- Variations in rotation rate are represented here in terms of zonal response parameter, $\kappa(\omega)$, which represents length of day variations (ΔLOD) normalized by the tide potential amplitude, $H(\omega)$, of a tidal component of frequency ω.

$$K(\omega) = -\left(\frac{\pi}{5}\right)^{1/2} \frac{\Delta\mathrm{LOD}(\omega)}{\mathrm{LOD}_0} \frac{3C}{MRH(\omega)} \qquad (1)$$

- **Figure 2** illustrates the scatter of the mass and motion contributions predicted by extended Mm and Mf models from **Model 1** and **Model 2**, as longer durations of T/P data are included into the models.
- The predicted inphase mass contributions are smaller than is predicted by equilibrium representations of Mm and Mf, and nonequilibrium contributions (e.g. motion and quadrature mass) are not negligible.
- The scatter of the Mf mass and motion predictions is much smaller than those of the Mm predictions.
- Short wavelength noise in the tide height models causes a larger scatter in the motion contributions than in the mass contributions, since velocities are inferred from derivatives of tide heights.
- This causes the predicted Mm motion contributions to be anomalously large, when they are actually expected to be smaller than Mf motion contributions since longer period tides should be closer to equilibrium.
- GERM data have an insignificant effect on the rotation rate predictions other than a small increase in the predicted Mf motion contribution.

Observed Variations in Rotation Rate

- **Figure 3** illustrates spectra of the SPACE98 length of day (LOD) time series after removing contributions from the atmospheric angular momentum (AAM), the long-period elastic solid Earth tide (SE, $\kappa = 0.2632$), the long-period equilibrium ocean tide (EQO, $\kappa = 0.0508$), and the **Model 2** Mm and Mf contribution.

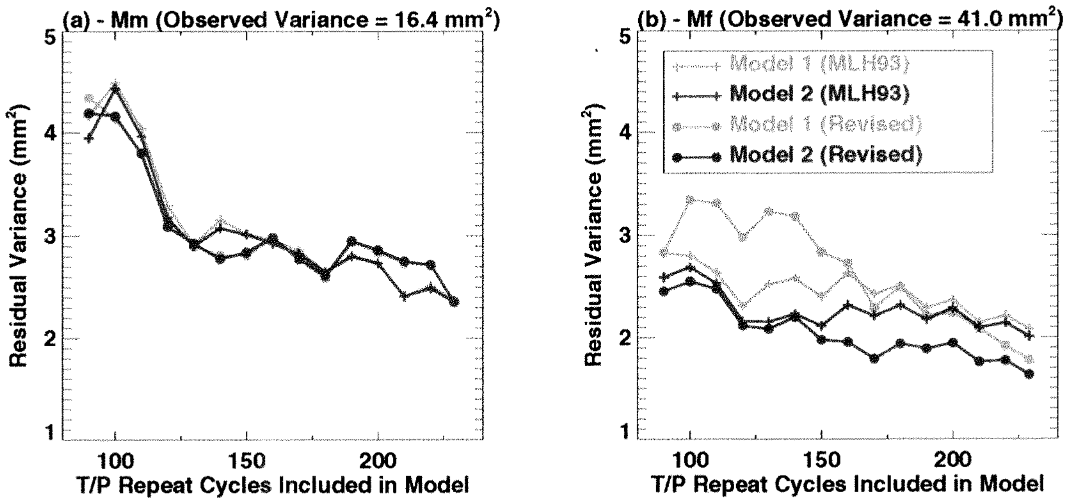

Figure 1. Residual variance between Mm and Mf ocean tides from **Model 1** and **Model 2**, and MLH93 tide gauge observations and revised tide gauge observations.

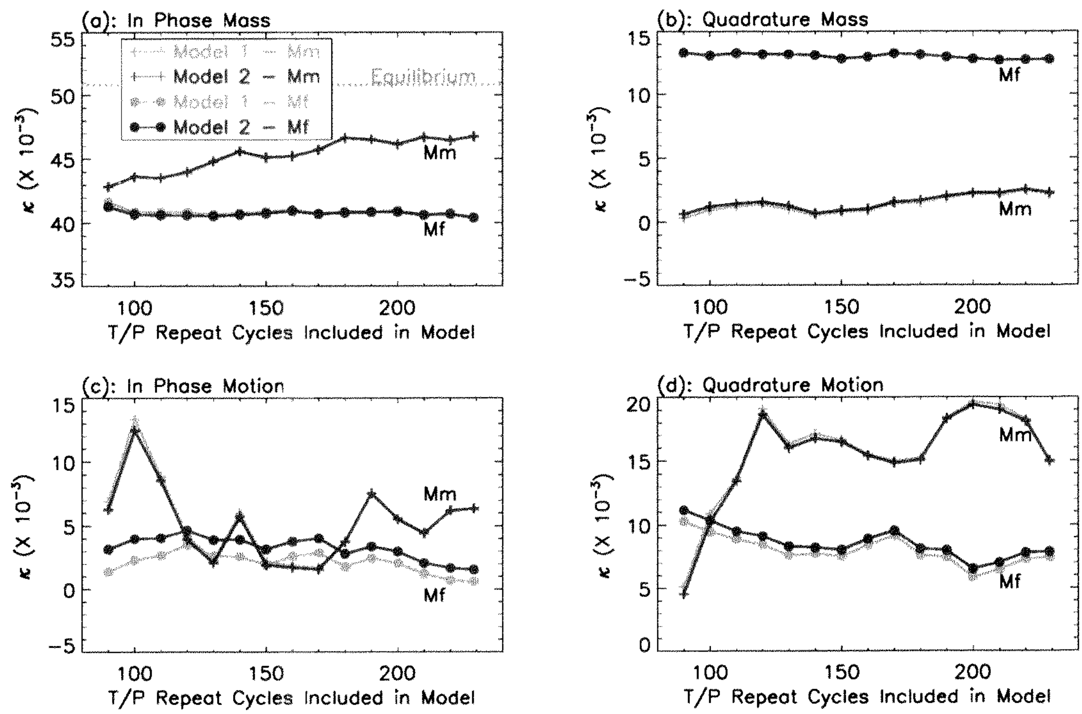

Figure 2. Scatter of Mm and Mf variations in Earth's rotation rate predicted by globally extended versions of **Model 1** and **Model 2,** as a function of the number of T/P repeat cycles of data included in the estimation of the models.

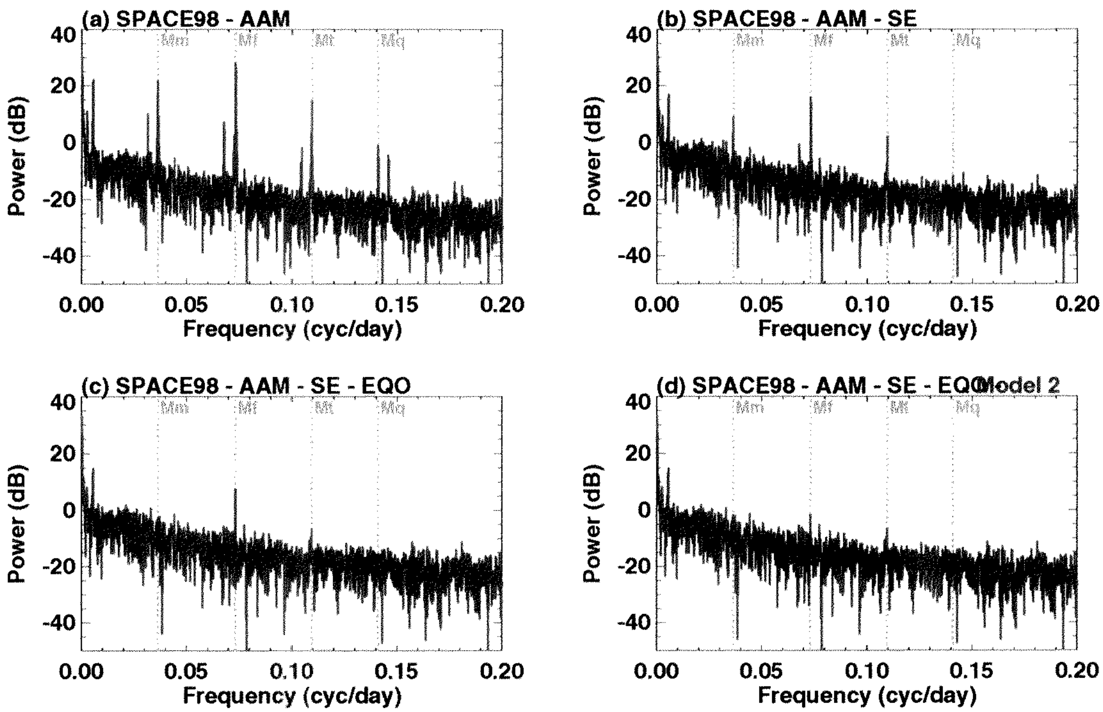

Figure 3. Spectra of SPACE98 LOD time series with contributions from: (a) AAM; (b) AAM and SE; (c) AAM, SE, and EQO; and (d), AAM, SE, EQO, and non-equilibrium Mm and Mf contributions from **Model 2**, respectively removed.

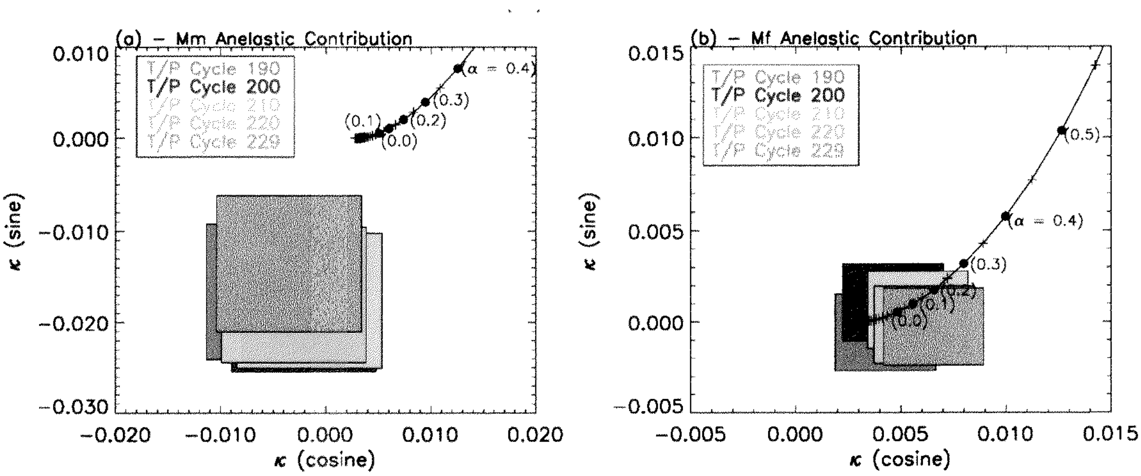

Figure 4. Comparison of anelastic contribution for various values of α using PREM (solid line with symbols), to that inferred by removing the SE and **Model 2** contributions from SPACE98 observations (colored boxes). The dimensions of the boxes are the sum of the formal errors in the observations and the scatter in the **Model 2** predictions.